

Figure 1 depicts a high level block diagram of a communication system including the present invention. Specifically, communication system 100 comprises a DSL network 110, a first transmission medium 112 and a remote terminal 102 housing a plurality of transmitters 104<sub>1</sub> and so on up to 104<sub>n</sub> (collectively transmitters 104). Each transmitter 104 has a respective encoder 106, a respective pre-coder  $P(f)$ , and a respective transmit filter  $G(f)$ . Each transmitter 104 communicates with a respective receiver 108 via a respective second transmission medium 114. Each of the receivers 108<sub>1</sub> through 108<sub>n</sub> includes a respective receive filter  $R(f)$ . Additionally, each receiver 108 is located at a respective subscriber A, B, C and so on up to N. Each of the respective second transmission mediums 114 are subject to respective channel impairments, generally denoted as  $H(f)$ .  $H(f)$  comprises transmission and/or cross-talk impairment of a channel.

During the initial "turn up" of a VDSL system, each of the transmitters 104 and receivers 108 goes through a training phase. Signals are communicated between respective transmitters 104 and receivers 108, and amplitude levels and shapes of the signals are measured. The communicated signals received by the receiving device 108 are predetermined signals, and deviancies from the expected values are noted received by the receiving device 108 and communicated to the transmitting device 104.

One factor that can result in a deviancy is far end cross-talk, which results when the energy from a signal in one communications path interferes with the signal in one or more other communication paths. That is, the energy level in the interfering communication path is communicated to the "non-interfering" communication paths resulting in distortion on the "non-interfering" communication paths.

An illustrative example of far end cross-talk occurring is when a subscriber X is having a conversation with a subscriber Y on a telephone line, and subscriber X and/or Y hears the telephone conversation of a subscriber Z who is not a party to subscriber X and Y's conversation. The two signals are

commingled and become distorted.

Referring to the communication system 100 of FIG. 1, a subscriber A receives an information "download" from, for example, the Internet (not shown). The downloaded information is communicated to the DSL network 110. Simultaneously, other subscribers (i.e., subscribers B, C and D) can receive the same or other information via respective downloads. The downloaded information can be data from a web page, email information and the like. The downloaded information is communicated via first transmission medium 112 to the remote terminal 102, which serves subscribers within, for example, a defined geographic region. First transmission medium 112 can be a fiber optic cable for transporting information between the DSL network 110 and remote terminal 102. Specifically, first transmission medium 112 is coupled between the DSL network 110 and each transmitter 104 via an intermediate device (not shown).

The encoder 106 performs data conversion on the downloaded information, converting the downloaded information from packets using realtime transport protocol (RTP) and the like to, illustratively, a CAP formatted signal. That is, a bit stream is converted into a symbol stream.

The CAP signal or symbol stream is, illustratively, a conventional CAP signal based on Quadrature Amplitude Modulation (QAM). In accordance with CAP, an impulse is generated which has two components. The first component is an in-phase signal while the second component is a quadrature phase signal. Each component can have a variable amplitude level, such as the four levels of the exemplary embodiment. By combining the two components, an impulse may be generated which has, illustratively, 16 unique combinations of in-phase signal amplitude and quadrature-phase signal amplitude. The 16 combinations are known as a CAP 16 constellation.

The CAP signal or symbol stream is communicated to a respective pre-coder  $P(f)$ . The pre-coder  $P(f)$  imparts a pre-coding function to the CAP symbol stream and communicates the "pre-coded" CAP symbol stream to a respective transmit filter  $G(f)$ . The transmit filter  $G(f)$  performs conventional

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wave shaping functions on the CAP symbol stream to produce a shaped CAP symbol stream. The shaped CAP symbol stream is then forwarded to a respective receiver 108 via a transmission medium 114. It is noted that the shaped CAP symbol stream is further adapted in response to a channel function  $H_f$ , which represents a logical signal path between the transmitter 104 and receiver 108. A receive filter  $R(f)$  at the receiver 108 shapes the received CAP symbol stream in a conventional manner. The function  $H(f)$  represents a mathematical model of the channel impairments that the shaped CAP symbol stream is subjected to as it traverses transmission medium 114. Such channel impairments include, for example, channel loss, cross-talk from other channels and the like.

As previously discussed, multiple transmitters can transmit information simultaneously. Hence, during the training period, information communicated via one communications path can cause interference to other communication paths. This is likely to occur on second transmission medium 114 which comprises, illustratively, a plurality of "twisted copper pairs" serving receivers located at separate and/or distinct locations.

Receiver 108 may receive a distorted CAP signal due to cross-talk from other transmitters. The transmitted CAP symbol stream is a predetermined signal where deviations are considered errors.

FIG. 2 depicts a block diagram of a Multiple Input Multiple Output (MIMO) system 200. The MIMO system 202 is an  $N$ -user data transmission system. The MIMO system 200 receives input CAP signals  $a^{(1)}(n)$ ,  $a^{(2)}(n)$  and so on up to  $a^{(N)}(n)$ . The MIMO system 200 comprises a transmit filter 204 which receives each of the input cap CAP signals  $a^{(1)}(n)$  through  $a^{(N)}(n)$  and imparts thereto a filtering function  $G(f)$ , communications channels having impairments 206 which are represented by a function  $H(f)$ , a summer 208 and receive filters 210 which implement a function  $R(f)$ . The output of the received filters 210 comprises output signals  $a^{*(1)}(n)$ ,  $a^{*(2)}(n)$  and so on up to  $a^{*(N)}(n)$ .

Using frequency domain expressions, the overall transfer function of the MIMO system 200, including transmit filters, receive filters and all direct